

and diameters from 200 to 900 μm against the nitrided surface of the springs at velocity from 40 m/sec. to 90 m/sec., so as to prevent generation of a microcrack in the surface layer by the projection and provide compression residual stress comparatively deep inside the springs; and

(c) projecting a number of fine metal particles having a mean diameter of all particles of 80 μm or less, a mean diameter of each particle in the range between 10 μm inclusive and less than 100 μm , a spherical or near spherical shape having no square portions, specific gravity from 7.0 to 9.0, and hardness which falls in the range between Hv 600 and Hv 1100 inclusive and is equal to or less than the hardness of the outermost surface layer of the springs after nitriding or low-temperature carbonitriding at velocity from 50 to 190 m/sec., while controlling an instantaneous temperature rise limit of the iron matrix excluding the nitride compound layer of the nitrided spring surface layer due to collision to be low enough to cause work hardening in the spring surface layer but not to cause softening due to recovery/recrystallization, thereby effectively work hardening and preventing generation of any microcracks in the surface layer to provide high compression residual stress and hardness.

2. (Amended) A spring surface treatment method, comprising the steps of:

(A) projecting a number of metal particles having diameters between 10 μm inclusive and less than 100 μm , a mean diameter of all particles of 80 μm or less, mean diameter of each particle of 10 to 80 μm , a spherical or near spherical shape having no square portions, a specific gravity of 7.0 to 9.0, and a hardness of Hv 350 to 900 against the surface of springs before nitriding at collision velocity in the range of 50 m/sec. and

160 m/sec. inclusive so that a temperature rise limit of the surface of the spring due to collision is controlled to be low enough to cause work hardening of the iron matrix of the springs but lower than the point at which recovery/recrystallization may occur so as to prevent generation of any microcracks;

(B) nitriding surface portion of the springs after the step (A);

(C) projecting hard metal particles having hardness which is lower than the hardness of the nitrided outermost surface layer and in the range of Hv 500 to 800, and a grain diameter of 200 to 900 μm against the nitrided surface of the springs at velocity of 40 m/sec. to 90 m/sec., so as to prevent generation of any microcracks in the surface layer by the projection and provide compression residual stress comparatively deep inside each spring; and

(D) projecting a number of metal microparticles having a mean diameter of all particles of 80 μm or less, a mean diameter of each particle in the range between 10 μm inclusive and less than 100 μm , a spherical or near spherical shape with no square portions, a specific gravity of 7.0 to 9.0, and a hardness which falls in the range between Hv 600 and Hv 1100 inclusive and is equal to or less than the hardness of the outermost surface layer of the spring after nitriding or low-temperature carbonitriding at the velocity of 50 to 190 m/sec., while controlling the instantaneous temperature rise limit of the iron matrix excluding nitride compound layer of the nitrided spring surface layer due to collision to be high enough to cause work hardening in the surface layer but lower than a point at which softening due to recovery/recrystallization may occur, thereby effectively causing work hardening and preventing generation of any

microcracks in the surface layer to provide a high compression residual stress and hardness.

3. (Amended) A surface treatment method comprised of the step of bombarding hard metal particles having hardness in the range between Hv 350 and 1100, specific gravity of 7.0 to 9.0, a mean diameter of all particles of 80 μm or less, a mean diameter of each particle in the range between 10 μm inclusive and less than 100 μm , and a spherical or near spherical shape with no square portions, on the surface of springs with the surface layer hardness of Hv 400 to 750, which hardness was obtained by one of low-temperature annealing for removal of macroscopic residual stress after cold forming, quenching and tempering after cold forming, and quenching and tempering after hot forming, at the collision velocity of 50 m/sec to 160 m/sec, while controlling the temperature rise limit of the spring surface layer due to collision to be low enough to cause work hardening in the spring surface layer but not to cause softening due to recovery/recrystallization and preventing generation of any microcracks in the surface layer which may deteriorate fatigue strength, thereby improving the hardness and compression residual stress of the surface layer which is 30 μm to 50 μm or less deep from the surface and resulting in improved endurance of the springs.

4. (Amended) A spring surface treatment method for preventing generation of harmful microcracks in surface layer which may deteriorate fatigue strength and for improving especially the hardness and compression residual stress of the surface layer

which is 30 μm to 50 μm or less deep from the surface, to improve endurance of the springs, the method comprising the steps of:

(A) projecting hard metal particles having hardness of Hv 350 to 900 and the particle diameter of 200 to 900 μm against the surface of formed and tempered springs having hardness of the surface layer of Hv 400 to 750 at the velocity of 40 m/sec to 90 m/sec so as to prevent generation of harmful microcracks in the surface layer and provide compression residual stress comparatively deep inside the springs; and

(B) performing the surface treatment method according to claim 3 on the spring surface after the step (A).

5. (Amended) A spring surface treatment method according to claim 1 or 2, wherein the particles having a mean diameter of all particles of 80 μm or less and a mean diameter of each particle in the range between 10 μm inclusive and less than 100 μm and the projection conditions of the particles are limited to the following:

hardness of projected particles: initial hardness being Hv 600 to 1100;

size of projected particles: initial mean diameter of each particle being 10 μm to 80 μm ;

mean diameter of all particles: 65 μm or less;

specific gravity of projected particles : 7.0 to 9.0; and

collision velocity against spring: 60 m/sec. to 140 m/sec.

6. (Amended) A spring surface treatment method according to claim 3 or 4, wherein the particles having a mean diameter of all particles of 80 μm or less and a

mean diameter of each particle in the range between 10 μm inclusive and less than 100 μm and the projection conditions of the particles are limited to the following:

hardness of projected particles: initial hardness being Hv 350 to 1100;

size of projected particles: initial mean diameter of each particle being 10 μm to 80 μm ;

mean diameter of all particles: 65 μm or less;

specific gravity of projected particles: 7.0 to 9.0; and

collision velocity against spring: 60 m/sec. to 140 m/sec.

8. (Amended) A spring produced from a circular cross-section wire or a non-circular cross-section wire by the steps according to claim 1 as essential steps, the spring being a coil spring made of any of steel types (1) to (4) containing respective chemical components, a compression residual stress of iron in a near surface layer by X-ray method being greater than 1700 MPa, sizes of a hard nonmetallic inclusion which may cause fatigue breaking of the spring and the hardness of matrix satisfying the following condition X or Y, the spring being a high fatigue resistance strength spring having a fatigue strength at 5×10^7 times of repetition satisfying expression (1) below:

in a repeated stress of $\tau_m \pm \tau_a$, when $\tau_m = 800 - x$,

$$\tau_a \geq (620 + x/5) \quad \text{----- (1)}$$

where

τ_m is mean stress,

τ_a is amplitude stress, and

x is a variable in the range of 0 and 150 inclusive, and

all in the unit of MPa,

condition X: controlling the hardness of the matrix at a depth in the range of 0.2 mm to 0.5 mm inclusive from the spring surface in the range between Hv 520 and 580 inclusive when the size of a harmful nonmetallic inclusion existing in the spring is less than 20 μm or 15 μm or less,

condition Y: controlling the hardness of the matrix at a depth in the range of 0.2 mm to 0.5 mm inclusive from the spring surface in the range between Hv 520 and 630 inclusive when the size of a harmful nonmetallic inclusion existing in the spring can be controlled to 10 μm or less, the steel types (1) to (4) being as follows:

(1) a steel type containing as essential components C: 0.50 to 0.80%, Si: 1.20 to 2.5%, Mn: $\leq 1.20\%$, and Cr: $\leq 1.80\%$ and iron and impurities as the remainder, including a steel type with one or two kinds of V: 0.03 to 0.60% and/or Nb: 0.02 to 0.20% added thereto;

(2) a steel type containing one or more kinds of Ni: 0.5% or less and/or Co: 3.0% or less in addition to the steel type (1);

(3) a steel type containing W: 0.5% or less and/or Mo: 0.6% or less and/or Al: 0.5% or less in addition to the steel type (1) or (2); and

(4) a steel type containing C: 0.05% or less, Si: 0.8% or less, Mn: 0.8% or less, Ni: 16 to 26%, Ti: 0.2 to 1.6%, Al: 0.4% or less, Co: 8.5% or less, Mo: 5.5% or less, Nb: 0.6% or less, wherein in addition to the above, 0.1% or less of B, Zr, and/or Ca may be added, and unavoidable impurities and iron as the remainder, wherein the unit of the chemical components is all mass percent.